THE DEVELOPMENT OF ALL-WELDED STEEL BRIDGE

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INTRODUCTION

Building frames with all connections made by arc welding have been in existence since 1920, and all welded bridges were first completed in 1928.

Welded steel frame construction has been developed entirely since the war, and all welded structures of considerable size have been built since 1925. Electric arc welding after many years of diversified use in the manufacture of steel products and the maintenance of equipment was first applied to heavy building frame construction in 1926. As early as 1920, however, all welded framing had been used for several years; and before that, welding had been utilized as an auxiliary process for some joints in building construction. The years between 1920 and 1926 did not see any marked extension in the use of welding for building construction or any large structures built by welding.

The Morgan Engineering Company of Alliance, Ohio, built some one story and two story buildings in the Middle West, including a 120 ton building at Canton, Ohio. The Chicago, Burlington, and Quincy Railroad constructed for its own use two or more small shop building in Illinois, using mainly reclaimed steel which would have been cut for scrap if welding had not provided a convenient means for assembling the material into new structures.

The serious commercial development of welding commenced in 1926, when the Westinghouse Electric and Manufacturing Company planned and constructed a heavy five-story factory building at its plant in Sharon, Pennsylvania. Seven hundred and ninety tons of steel were required, as compared with about nine hundred tons in an alternative design prepared for riveting. In dimensions, number of stories, weight of steel and amount of welding, the Sharon Building was many times larger than any previous welded structure. Beams and girders were made continuous where possible, and this building included the first welded plate girders.

During the years 1926-1927 a number of welded buildings were erected. In 1927 the Chicago Great Western Railroad reinforced its Missouri River bridge at Leavenworth, Kansas, using about 7500 lineal feet of welding to attach one hundred tons of new steel to old members. (Ref. 1.)

By 1928 the use of electric welding to reinforce existing bridges was an established practice and with the successful demonstration of the practicability of using electric welding to replace rivets in the Sharon Building, it was inevitable that electric welding would replace rivets in bridges.

In the winter of 1927-28 at Chicopee Falls, Massachusetts, the first all welded truss bridge was constructed. It is a through-truss bridge with an extreme angle of skew and span of 135 feet. This bridge used for freight traffic only, is one-third lighter than a corresponding riveted bridge. This saving in weight is attributable to (a) elimination of gussets at minor joints, (b) utilization of gross instead of net sections of tension members, (c) reduced sections of floor stringers made possible by continuous joints. (d) miscellaneous minor items including reinforcement and lighting of top lateral and transverse bracing, elimination of rivets and elimination or lightening of numerous connections other than truss joints. Slot welds used for the first time in structural work proved at this time to be very valuable in saving of steel by limiting size of gusset plates and were found easy to make. After the bridge was in service for about one week, one of the butt welds in the bottom chord splices cracked. The cracked weld was cut out, examined and found to be satisfactory in quality. The cause for the cracking was laid to residual stresses caused by faulty design. The consulting engineer, Gilbert Fish, believed that tension but welds should be avoided in dynamic design. After a year of service two welds in other parts of the structure cracked. These were repaired and up to 1933 there has been no further trouble. (Ref. 1.) Evidently at that time welding material, technique and design had not been developed to be entirely successful for repeated loadings. The effect of repeated loadings on welded joints has been the subject of much research in recent years.

Welded bridges developed in practically all countries between the years 1928 and 1932. In 1929-1930, the first all welded bridge was built in Europe. This bridge was constructed by the Polish Government at Lowiez, Poland, for a highway crossing over the Sludevia River. The bridge has a span of 88½ feet between supports, and is 14 feet high, and is of the half thru camelback type. The chords are built up members of flat plates welded together, and the diagonals are built up of channels with batten plates. This bridge differs in this respect from the Chicopee Falls bridge in that the latter uses rolled H sections for the main members and angles for the minor members. The Polish bridge weighed 55 tons and if made with rivet joints, it would have weighed 70 tons. However, the cost is estimated about the same. Welding was facilitated by the use of jigs and the stringers were conveniently made continuous by welding. (Ref. 2.)

1928 saw one of the first all welded plate girders bridges erected in America at East Pittsburgh, Pennsylvania. This bridge was designed for a 185,000 locomotive and weighed 39,300 pounds. Girders were of 53 feet span and five feet deep. Flat plates were used exclusively for all members - flanges, web and web stiffners. Floor beams, as well as stringers, were welded in place. (Ref. 3.)

In 1929 the German Railways erected a welded bridge 33 feet long. (Ref. 4.)

Use was made of welding in the erection of railway bridges and underpasses of an extension to an electrified railway system running out of Melbourne, Victoria, Australia, in 1929. At Scotchman's Creek the floor deck was welded to a 48 feet, 9 inches through riveted plate girder bridge. (Ref. 5.)

A number of welded bridges have been built in Australia. In 1933, W. T. B. McCormack, Chairman of the Victorian County Roads Board, reported that three arc welded bridges were built up to that time. Alternate rivet and welded designs were prepared and in each case the lowest bid was for a welded structure. These bridges were the Sunday River bridge, the Swan Reach bridge, and the Snowy River bridge.

The Sunday Creek bridge was designed and constructed in 1930 and consists of two continuous steel truss five supports carrying a 22 feet concrete deck. The spans are 52 feet at ends and 65 feet for the central portion. The trusses were shop fabricated and bolted field species; it was believed, however, that welded field splices would have been more economical.

Designed and constructed in 1931, the Swan Reach bridge is a structure with a total length of 406 feet, made up of six welded plate girders spans of 62 feet, and a central span of 43 feet. Rolled beams were used for the central portion which is designed as future left span. Flat plates were used exclusively for the weldded plate girders. The total weight of steel was 101 tons and 16,000 lineal feet of welding were used consisting single run, 10 gage electrode.

The Snowy River bridge was designed in 1931 and constructed in 1932 on a mountain road 95 miles from the nearest seaport. No railway facilities were available. It being built essentially for livestock is also designed for a ten ton truck load. The bridge, a continuous Warren truss type, 750 feet long, consists of four intermediate spans of 135 feet each and two end spans of 105 feet each. The trusses were 10 feet deep and 10 feet apart and built of plates, angles, and channels. Fabrication was necessarily made at the site owing to its remoteness.

An interesting application of welded trusses was made in the Pykes Creek bridge, built in 1928-29, in Victoria County, Australia, where steel trusses were used as part of the main reinforcement for a concrete bridge. The bridge, 246 feet long, was made up of 40 foot end spans, two 54½ feet intermediate spans, and one 56½ feet center span. (Ref. 5.)

In the fall of 1931, the largest all welded bridges in the world at that time was constructed in Prague, Czechoslovakia. This bridge, a Warren type with verticals, had a span of 161 feet, 3 inches, and a height of 21 feet, 11 inches. The trusses were 27 feet, 4 inches apart and connected by 31 inch plate girder floor beams. Rolled I beam stringers were made continuous by welding to the webs of the floor beams. At this time there were no regulations for welded bridges in Czechoslovakia and provisional regulations were made by the Skoda Works in whose plant the bridge is. The main members were built up of plates and rolled members since at that time there were suitable rolled sections available. Arc welding was by direct current with uncoated wire electrodes. In all there were 15,158 feet of welded seams on the bridge of which 2,165 feet were welded in the field. (Ref. 6.)

At Leuk, Switzerland in 1930, a welded bridge of 37 tons, with a span of 122 feet, was erected. It was a deck bridge of Warren type with verticals. (Ref. 6.)

The first major bridge project in California to use welding was constructed in 1932 as a highway passing over a railroad on the Yosemite Valley highway near Merced, California. The bridge, 1380 feet long, used welded I sections and welded angle sway braced copper bearing steel pile bents. Electric welding was used throughout except where stringers were riveted to the floor beams. (Ref. 7.) The use of welded I beams for bridges with welded fittings has been used quite extensively in America.

The Pennsylvania state highways have found it economical to replace their old highway bridges with rolled I beams, and a solid flooring of wood panels surfaced with a bituminous mastic. The design in 1933 was an all welded structure with steel curbs and guard rails. I beams are laid parallel to direction of travel and tied with suitable diagonal bracing. Welding is done in the field and existing foundations are used when practicable. (Ref. 17.)

In 1933 a welded lift bridge was built in Japan. The lift span contained two 69 feet, 10 panel Vierendeel trusses, 8 feet, 2 inches deep. All members of the trusses were built up of plates. In most of the other bridges mentioned, the welding was made continuous but in the bridge the welding was only continuous near the panel points and intermittent elsewhere. The argument given for light continuous welds is that they seal the joints and thus are more corrosion resistant than, for example, riveted joints. In this bridge the counterweights were placed in the towers which were 40 feet high, and lifting machinery was placed within one of the abutments below the roadway. All of the 4,264 linear feet of welding was done in the shop. The weight of the structural steel was about 30 metric tons. (Ref. 8.)

Many welded truss bridges and welded plate girders have been built in the U.S.S.R. At Stalinsk, Russia, a welded bridge of 227 feet span and 59 feet width to carry tramway cars and highway traffic across the River Abushka, reputed at the time to be the world's largest welded bridge, was opened to traffic in 1934.

A report in 1934 discloses that two 150 feet shop and field welded bridges have been built, as well as several railroad girder bridges. A test program was made to determine the strength of welded connections under actual railroad locomotive loadings. (Ref. 10 and 16.)

In 1934 a two hinged welded steel arch bridge was built in Czechoslovakia. It was made up of two arch ribs 20 feet, 8 inches apart, with a rise of 35 feet. Steel columns and beams made up the superstructure which supported a concrete and granite block roadway. This structure weighed 110 tons of which 47 tons were arch rib. Over six miles of continuous weld was made with bail and coated electrodes. (Ref. 15.)

In 1934 the first all welded highway bridge in England was completed over the Tees River near Newport. The frame consists of five shop fabricated girders welded at the site to pin supported columns and plate girder floor beams, making a five span continuous rigid frame bridge. (Ref. 23.)

Electric welding has been used extensively in Belgium for use with the Vierendeel Bridge. In 1932-33 the first welded Vierendeel bridge was built over the Albert Canal. It had a span of 208 feet. The experience with Vierendell bridges has been so satisfactory that most of the bridges are of this type. The earlier bridges were field riveted while the later ones were both shop and field welded. By 1935 there were twenty-six welded Vierendeel bridges in Belgium. Of these, all were highway except five which were railroad bridges. The spans ranged from 104 to 208 feet, and the weight ranged from 95 to 448 tons.

By 1933 welding had not been adopted by the Belgium railroads although the question was receiving serious attention and testing was being made on the behavior of welds under dynamic loads. Welding and flame cutting made fabrication of the Vierendeel truss easier. Members were generally either rolled of built up H sections. Welds are usually continuous. (Ref. 9.)

An unusual example of the use of welded Vierendeel trusses is the 117 feet swing bridge constructed in 1932 at Ghent. (Muide). Belgium providing a 71.5 foot span over the navigable channel on one side of the pivot pier. Welding and Vierendeel trusses are a natural combination from the standpoint of economy, aesthetics, and technical design. In 1936 the number of welded Vierendeel bridges were reported to be thirty five, either constructed or under contract. Heavily flux covered electrodes and a.c. welding have been used for all these Belgium bridges. (Ref. 10.) That the welding Vierendeel truss has been used more in Belgium than any other country in the world, is, no doubt, due to the influence of Professor A. Vierendeel of the University of Louvain, who invented the truss in 1897.

Since 1930 more than three hundred all welded bridges have been put into service in Germany. About half of them are for railroads and the other half for State Motor Roads which are also under the German State Railways management. (Ref. 11.)

Welding development began in 1929 with the use of structural sections patterned closely after those used in riveted construction which soon gave way to simpler sections composed of flat flange plates, fillet welded directly to the web. (Ref. 10.)

Of the welded railroad bridges in Germany, the plate girder type only had been accepted so far. For highway bridges, however, the rigid arch type is also accepted. No railroad truss bridge of truss construction has been put in service in Germany. (Ref. 11.) The development of welding for bridges has been based upon extensive fatigue research carried out between 1930 and 1936. Every detail of welded construction was determined with regard to fatigue. (Ref. 11.)

In Germany and Sweden, the use of specially rolled flange plate sections has been part of their development. Some of these are illustrated below:

The so-called Wuest profile had an output of about 16,000 tons up to the beginning of 1936. (Ref. 10.) These are available in thickness up to 3½ inches and in width up to 37-7/8 inches. At present these are the most popular type for construction of long span bridges. These are adopted from the result of fatigue research, namely, to avoid concentration of stress and to have transition from one structural component to another as thoroughly rounded as possible.

The German plate girder bridges have been unusually long. In 1935 the Zeigelgraben railway bridge was built with span of 174 feet. For the girders the Nasenprofile plate flanges were used and were rolled within one piece so as to eliminate any welding of the flanges. At the bridge works the flange and web plates were assembled in circular clamps which rotated on rollers as required to bring the welds successively into the most convenient position. It is interesting to note that for most of the welding bare wire electrodes were used. Only a few high stressed joints were welded by heavily coated electrodes. Some of the girders have been fabricated with automatic welding machines. The Schlacthof Bridge in Dresden, completed in 1933, which at the time was the longest welded bridge in Europe, has a total length of 1040 feet and is composed of thirteen spans averaging between 72½ and 80 feet. The main girders and floor beams were built from plates shop-welded by automatic machines. (Ref. 12.)

In the Stresalund bridge, finished in 1936, plate girders were made continuous over five spans. The total length of this bridge is 1771 feet, 8 inches, appears to indicate that it is the longest all welded railroad bridge built so far, and perhaps the single span of 177 feet, 2 inches, may be also a record for a welded main line railroad bridge. (Ref. 11.)

Another interesting bridge is the Kaiserberg highway bridge near Duisberg, built in 1936. The bridge is of the rigid arch type of 338 feet span and possibly the longest span for an all welded bridge. (Ref. 11.)

The bridges built at Ludersdorf in 1936 for the State Motor Roads are stated to be the longest all welded bridges in Germany, not only for their total length, but for their single spans. The main girders are continuous over six and seven spans, respectively. The maximum single span is 204 feet and its total length is 2,452 feet. The southern bridge is only continuous over four spans but the maximum single span is 218 feet. Triangular rib flange (Wulst profile) plates were again used for main girders. It is probably the first time that girders as long as 1,328 feet were continuously welded on site. These girders are 9 feet, 3 inches high. (Ref. 11.)

In the early stages of structural welding the problem of fatigue resistance were given little attention. It was not until 1934 that the regulations of the German State Railways were made to include a fatigue factor depending upon the rates between maximum and minimum force. Since 1930, from a 33 feet span railroad bridge more than 30,000 tons of all welded bridge has been built in Germany. (Ref. 11.)

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In 1936, a welded Vierendeel span of 175 feet with a 25½ foot roadway and two sidewalks has been constructed over a railroad at Nerth, Holland. (Ref. 13.)

On the Vienna-Budapest Highway a welded truss bridge of about 179 feet span was constructed in 1934 over the Rabia River at Gijor, Hungary, involving over 110 tons of high strength steel. (Ref. 10.)

In Burlington County, New Jersey, over the Rancocos Creek, in 1936 was constructed an all welded swing bridge. The 160 foot swing center span is flanked by two 112 feet, 8 inches approaches. The trusses 36 feet apart are of the Pony type. Carnegie beams are used throughout. The bridge weighs 470 tons and all welding was done with covered electrodes. Over 10,200 linear feet of equivalent 3/8 inch weld were used. (Ref. 18, 19.)

In 1936 a 70 foot girder bascule bridge was built for the Florida East Coast Railways at Jupiter, Florida. Alternate designs were prepared and it was found that a saving in 20% of the counterweight tonnage gave the welded bridge the advantage. All joints were both shop and field welded with continuous weld. Exclusive of seal welds, all welds were 3/8 inch fillet except for the lateral bracing which was 1/4 inch. The girders replaced a former wrecked span and were erected without interruption of train service. (Ref. 14.)

What was believed to be the longest arc welded bridge of its kind was erected in 1936 over the Raquette River on the International Highway near Messena, New York. It consisted of two 150 foot through Pratt spans, and a forty foot beam span approach. The details were especially designed so that the welder would find the joint easily accessible. 3/8 inch single pass fillet welds were used throughout. Bare wire electrodes were used throughout except at double V splices in the upper chords. The steel weighs 300 tons and over 3,000 feet of welding wire was used. (Ref. 22.)

The new highway bridge across the Ste. Anne River at the village of La Parade, Quebec, officially opened October 25, 1936 is an all welded structure consisting of six continuous deck girder spans of 107 feet which replace three pin connected through spans of twice that length built some forty years ago. The main girders were made of plates while the floor beams were rolled sections and stringers were made continuous by welding through the beams. Welding was found to affect a saving of 15% over rivets. The total weight of the structure amounted to 318 tons, of which 183 tons represents the main girders. 6,460 pounds of covered welding electrodes were used in the shop and 1,780 pounds in the field. (Ref. 20.)

The Sullivan County bridge near Livingston Manor, completed in 1937, marks the first use of welded plate girders for highway bridges in New York State. The bridge consists of two 71 feet, 8 inches long by 72 inches deep plate girders, 22 feet, 8 inches center to center. Rolled steel sections were used for floor beams. Heavily coated electrodes were used, and it is estimated that welding saved 23% in weight over riveted construction. (Ref. 21.)

During the past ten years the materials, the technique, and equipment for electric welding have developed considerably. These ten years have seen the development of the first all welded bridge at Chicopee Falls to the large bridges in Germany.

American practice has tended to use existing rolled sections for truss bridges and as yet, have not developed any special sections for plate girders bridges. During this period the electrodes have developed and American and British practice have tended to use covered electrodes. The later Belgium bridges have also shown a trend toward covered electrodes.

The German trend has been toward bare wire electrodes and use of automatic welding machines. For a number of years crane girders have been welded automatically in America. Special sections suitable for welded plate girders have been developed in Europe. The German trend has been toward X-ray inspection of welds for their bridges, but American practice does not seem to believe that under present day methods and materials that it warrants the additional expense. However, for pipe lines, etc. X-ray inspection is quite common. Progress in the application of arc welding to industrial work has become so extensive and so far advanced in the United States that this country leads all others in the use of this process for mechanical equipment. (Ref. 60.) However, in the field of structural engineering, particularly bridge engineering, the advancement has not been so outstanding.

However, greater interest is being shown toward welding than before. The 1936 American Association of State Highway Officials specifications for bridges, includes regulations for welding. In 1936 the American Welding Society provided a specification for bridges.

In 1938 the James F. Lincoln Arc Welding Foundation offered prizes for the design and practical application of welding to all branches of industry, including bridge engineering. (Ref. 24.)

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